SHALLOW SHEAR WAVE VELOCITY PROFILING OF POORLY CHARACTERIZED EARTHQUAKE SITE-RESPONSE UNITS IN URBAN SALT LAKE VALLEY

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Technical Abstract

Previous to this work, five quaternary earthquake site-response units where identified and mapped in Salt Lake County (Ashland and Mc Donald, 2002). These site response units were mapped based upon geology and 98 available shear wave velocity profiles. Of these 98 profiles, 68 were in the QO1 unit. Twenty were in Q02, and 10 were in Q03. Profiles in units Q02 andQ03 were also geographically limited. No measured profiles were located in the Q04 or Q05 units. For this work, 30 additional shear wave velocity profiles were measured in units Q02, Q03, Q04, and Q05. Fourteen additional profiles were measured in nearby counties. Based upon this work, it was determined that the original Q03 and Q04 units are indistinguishable. Based upon this finding the Salt Lake County site response map was revised using four site response units. A t test was used to show that the differences in mean velocity of each unit is statistically significant. The additional 14 profiles where measured in Utah, Davis and Weber counties, where practically no shear wave velocity profiles where available. These few profiles suggest that significant differences in average shear wave velocity may exist between similar geologic units in Salt Lake County and the three other counties. Major drainages in Weber and Davis County erode Tertiary sedimentary and Precambrian metamorphic rocks, whereas the major drainages in Salt Lake Valley mostly erode Tertiary granitic and Paleozoic through Mesozoic sedimentary rocks. As a result, the valley fill in other Wasatch Front basins is finer grained than in Salt Lake Valley. Another factor contributing to the finer grained valley fill in other Wasatch Front basins is that deposition occurs in distal parts of large, low gradient drainages such as the Provo, Weber, and Ogden Rivers. In Salt Lake County, shorter, steeper drainages generally deliver coarser sediment.

Non-Technical Abstract

Previous to this work, five quaternary earthquake site-response units where identified and mapped in Salt Lake County (Ashland and Mc Donald, 2002). Each of these units was assumed to have a reasonably homogeneous average shear wave velocity in the upper 30m. The average shear wave velocity in the upper 30 m is an indicator of how the site conditions will affect the amplitude of earthquake shaking. However, few actual measurements of shear wave velocity were available in Salt Lake County, and the measured profiles were largely limited to two of the mapped units and had a poor geographical distribution. For this work, 30 additional shear wave velocity profiles were measured in the Salt Lake County. Fourteen additional profiles were measured in nearby counties. Based upon this work, it was determined that two of the original units are indistinguishable. Based upon this finding the Salt Lake County site response map was revised using four site response units. Statistical analyses were performed on the data set to evaluate the variability within each unit, and the statistical significance the data. The additional 14 profiles were measured in Utah, Davis and Weber counties, where practically no shear wave velocity profiles where available. These few profiles suggest that significant differences in average shear wave velocity may exist between similar geologic units in Salt Lake County and the three other counties. Differences in geology between the drainages in the Salt Lake Valley and other Wasatch Front valleys might explain the differences in average shear wave velocity.

Chapter 1

Introduction

For this project, we measured 30 new shallow shear wave velocity profiles in poorly characterized earthquake site-response units in the urban Salt Lake Valley, and 14 new shallow shear wave velocity profiles in poorly characterized earthquake site-response units in other urban areas along the Wasatch Front. The data generated in this study increased the shear wave velocity profile database by about 50% in the Salt Lake Valley. This work resulted in a significant realignment of the mapped earthquake site response units in the Salt Lake Valley, and provides the only shallow shear wave velocity data available in urban areas outside of the Salt Lake Valley. This study will reduce loses from earthquakes in the United States and specifically along the Wasatch Front. The measured shear wave velocity profiles will increase the accuracy of shallow subsurface characterizations. These improved characterizations will:

- improve planning and hazard mitigation by enhancing the accuracy of ground motion models
- improve emergency response during earthquakes by providing more accurate ShakeMaps (Wald et al., 1999)
- improve building and bridge safety by facilitating International Building Code (IBC) procedures for calculating base shear
- improve seismic safety in other rapidly growing areas of the Wasatch Front by extrapolating properties of similar geologic units

Shear wave velocity profiles of the near surface (upper 30 meters) are important predictors of site amplification factors for earthquake shaking (Borcherdt, 1994; Joyner and Fumal, 1985; Boore et al., 1993). These site amplification factors describe how the surficial strata amplify (or attenuate) ground motion during an earthquake. Characterization of shallow soils for prediction of earthquake shaking is an important part of NEHRP's mission, as emphasized in the aftermath of the 1994 Northridge Earthquake (FEMA, 1996). The purpose of this project was not to measure shear wave velocity profiles on a site-by-site basis; rather to characterize site-response units that have already been identified based upon geologic origin. Thus, with a relatively small number of measurements, we were able to improve ground motion predictions throughout a large region where similar deposits are found.

A significant seismic hazard exists in the urban Salt Lake Valley. The probability of a M 6.5 to 7.5 earthquake in Utah's Wasatch Front region is 25±10% in the next 50 years (Pechmann, written communication 2002). Eighty-five percent of the state's population lives in this corridor.

For a region with such a high earthquake hazard, relatively little was known of the shallow shear wave velocity structure. Before this study, of four generalized valley-margin deposits in the Salt Lake Valley/Wasatch Front urban corridor, shear wave velocity profiles existed for only two: lacustrine sand and lacustrine-alluvial gravel. The shear wave velocity profiles in these two units were limited in number and restricted geographically, with about 90 percent of the profiles located in the northeast part of Salt Lake Valley. For the other two mapped valley-margin units, glacial and older (pre-Bonneville) alluvial fan deposits (Ashland and Rollins, 1999; Ashland, 2001), shear wave velocity profiles were altogether lacking.

Preliminary site-response mapping of Salt Lake Valley (Ashland and Rollins, 1999; Ashland, 2001) used the available shear wave velocity profiles and regional comparisons of geologic units to calculate the average shear wave velocity in the upper 30 meters (Vs30). Ashland (2001) used statistical tests to regroup Salt Lake Valley site-response units into eight categories with distinct mean Vs30 values. For all but two units, the calculated values were statistically insignificant or are based on regional mapping. Based upon this work, the five quaternary site response units mapped by Ashland and Rollins (1999) and Ashland (2001) have been realigned into four site response units.

Whenever possible, strong-motion stations of the Advanced National Seismic System (ANSS) were used as sites for this project. We were able to measure shear wave velocity profiles at XX ANSS sites.

The Spectral-Analysis-of-Surface-Waves (SASW) method was used to measure shear wave velocity profiles to depths of 30 to 60 meters. The SASW method is a nonintrusive seismic method utilizing the dispersive nature of Rayleigh-type surface waves to measure shear wave velocity profiles at soil and rock sites (Stokoe et al., 1994). The SASW method has been used for many years to successfully predict earthquake site response (Stokoe et. al., 1997). Profiling using surface wave methods, other than SASW, has provided poor agreement with other seismic methods (Wills, 1998; and Boore and Brown, 1998). However, shear wave velocity profiles measured using the SASW method consistently correspond closely to those measured using other seismic methods (Brown, Boore and Stokoe, 2002). At sites where bedrock or other stiff layers were encountered within the top 30 to 60 meters, SASW testing was supplemented with P-wave refraction testing. The refraction tests were used to obtain an improved estimate of the shear wave velocity of the stiff layer.

This report is organized as follows. Chapter 2 contains a brief discussion of the geophysical testing methods employed to measure shear wave velocity profiles at each site. Chapter 3 contains the results geophysical testing at each site. Chapter 4 contains a discussion of how the testing was used to modify the earthquake site response units in the Salt Lake Valley and elsewhere along the Wasatch Front. And, Chapter 5 summarizes the conclusions of this research and details additional work that needs to be done to improve the the velocity model along the Wasatch Front.

Chapter 2

Geophysical Testing Methods

Two geophysical methods were used together to determine the shear wave velocity profiles at 44 sites in the Salt Lake Valley and surrounding areas. The primary method was the Spectal-Analysis-of-Surface-Waves (SASW) method. SASW method was supplemented with limited P-wave refraction testing. For both methods, a trailer mounted, mobile drop- weight was used a wave source. A brief description of both the SASW and refraction testing procedures and data analysis procedures used to analyze both sets of field data is included in this chapter.

2.1 The SASW Testing Method

The SASW method is a nondestructive, nonintrusive method for measuring shear wave velocity profiles at soil and rock sites. The SASW method uses a source that applies a vertical excitation to the ground surface to generate Rayliegh-type surface waves, and an array of vertically oriented sensors to measure the propagation velocity of the surface waves. A detailed discussion of the SASW testing and analysis procedure can be found in Stokoe, et al. (1994), and a more detailed discussion of the procedures and equipment employed for this work can be found in Gilbert (2004).

2.1.1 SASW Wave Source

The primary source used in SASW testing for this project was a trailer mounted 2040-kg drop weight. This source was designed and built at Utah State University to generate surface waves with sufficient energy and the appropriate frequency content for SASW profiling to depths of 30-60 m (Cowley, 2002). Fig. 2.1 shows a photograph of the drop weight source. The source is designed to be highly mobile, for rapid deployment, and to be safe for testing in urban environments. The trailer mounted source includes a gasoline powered generator, air compressor, tripod, hoisting system, a pneumatic quick-release system, and an inertial force measurement system.

2.1.2 SASW Field Testing Geometry

The basic testing procedure followed by the USU field crew attempted to maximize the collection of reliable, quality data in a reasonable amount of time. Receiver spacings were redundant and both forward and reverse array lines were tested for almost half of the sites, all in order to verify data.

Upon arriving at a site, a relatively flat, straight line 120 meters (400 ft) long for the receiver array was selected. With the seismic trailer source positioned at one end of the line, a tape measure was stretched out 120 meters (400 ft) and secured, along which receivers were placed. A hand held gps sensor, Garmin GPS III Plus, placed at the centerline of the tape, calculated the UTM coordinates of the testing array. The datum used was WGS 84.

Fig. 2.1 USU Trailer mounted Drop-Weight Source

A four channel, Hewlett Packard 35670A, dynamic signal analyzer shown in Fig. 2.2, was used to collect data from three 1 Hz geophones (seismometers) model L4-C manufactured by Mark Products. Cables were run from all three receivers back to channels 2 through 4 on the analyzer. Channel 1 was used to measure the force output of the drop-weight.

The use of three receivers allowed two different spacings to be measured for a given series of drops. Fig. 2.3 shows the testing array. Receivers R1 and R2 are used to measure the spacing d1, while receivers R2 and R3 are used to measure the spacing d2. Both the forward and reverse testing directions are shown in Fig. 2.3.

It should be noted that the material tested for both directions are not necessarily the same. In the forward direction, the soil between R2 and R3 partially overlaps what is tested in the reverse direction. For the shorter spacing, d1, forward and reverse directions are not sampling the same soil.

Reversing the direction of a testing array is done to minimize the effect of a phase shift due to equipment differences and coupling differences between the receiver and the soil. If the same soil is not tested using both the forward and reverse directions, the phase shift may be due to both effects previously described, but also may be heavily affected by lateral variability in the underlying material. Due to both setup time limitations and space limitations, the receiver geometry shown in Fig. 2.2 was utilized, even though a common centerline was not used for the forward and reverse directions. The resulting configuration does provide insight into the global, or lateral variability of a site.

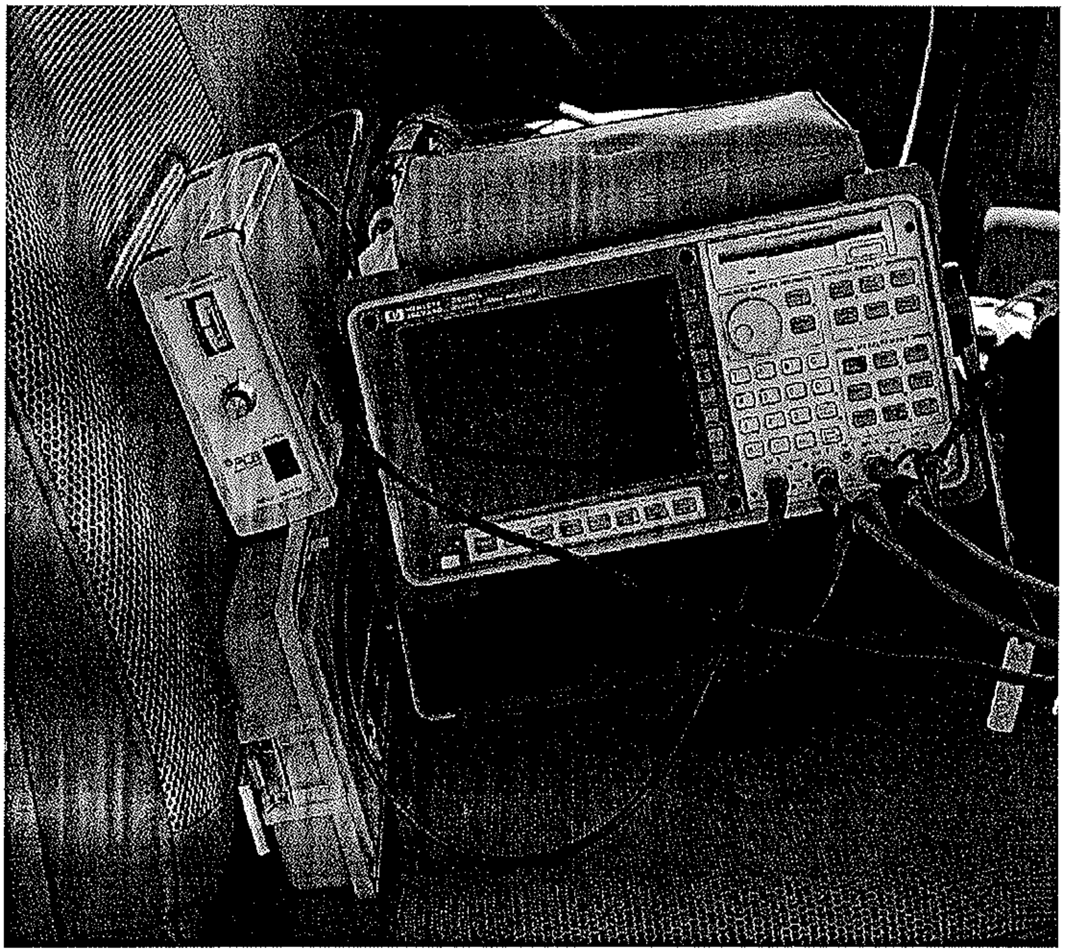

Fig. 2.2 Hewlett-Packard 35670A Dynamic Signal Analyzer Used for Data Acquisition and Analysis

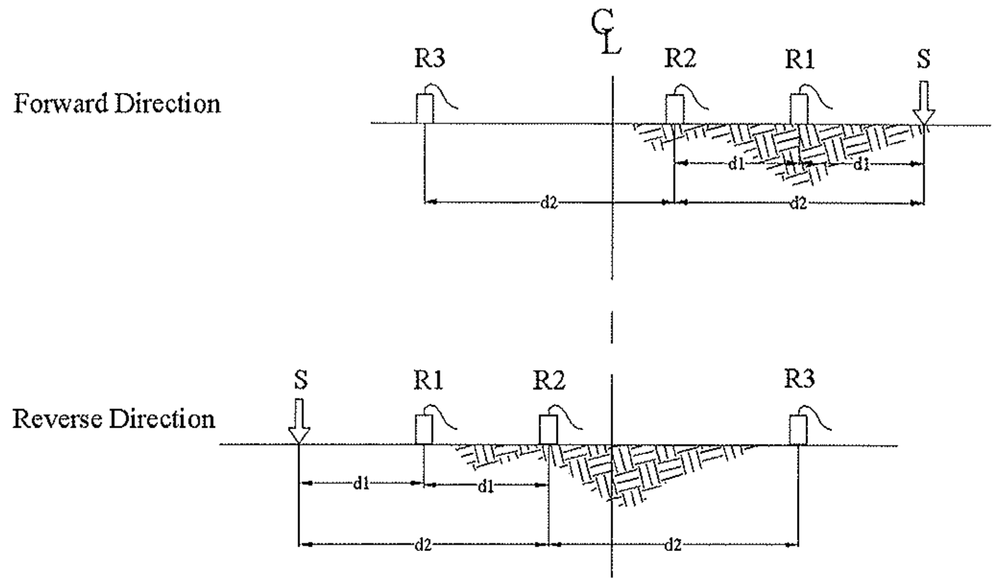

Fig. 2.3 General SASW Field Testing Source-Receiver Geometry used in this Work

Three different receiver set-ups were used in each direction direction, with the drop weight acting as the source. The first used receiver spacings of 61.0 and 30.5 meters, the second used receiver spacings of 30.5 and 15.25 m, and the third used receiver spacings of 15.25 and 7.63 m. Thus, three of the receiver spacings were repeated twice.

After completing the three receiver configurations using the drop weight, shorter spacings were tested using an instrumented sledgehammer as the source. The sledgehammer produces higher frequencies, which sample shallower material than the drop weight. Receiver spacings of 6, 3, 2.4, and 1.2 m were used with the hammer testing. Testing was performed in the forward and reverse direction for all hammer testing.

2.2 SASW Data Analysis Method

A unique method of collecting and calculating data to produce phase plots was utilized for the SASW testing. Phase plots were calculated and shown in the field by the dynamic signal analyzer, using information from the receivers as well as the source. Using the source function verifies that the phase shift between receivers is correlated to the source signal and not affected by ambient noise.

The power spectra and cross power spectra determine the phase shift and coherence function between two receivers. The source signal, measured by the accelerometer embedded in the drop weight, is applied in calculating these values by using a transfer function (*H*). The transfer function represents the ratio of the cross power spectrum and the power spectrum of two records.

Consider the testing setup of a source and two receivers. Records in the time domain of the source and both receivers (s, r_1, and r_2) are converted to the frequency domain (S, R_1 and R_2) using FFT. The transfer function between the source and the first receiver, R_1 is describe in Equation 2.1.

$$H_{SR_1} = \frac{R_1 S^*}{SS^*} \tag{2.1}$$

where: H_{SR_1} is the transfer function between the source and the first receiver,

R_1 is the complex vector in the frequency domain for the first receiver,

S^* is the complex conjugate in the frequency domain of the record for the source, and

S is the complex vector in the frequency domain for the source.

A transfer function between the source and the second receiver is defined in like manner, as shown in Equation 2.2.

$$H_{SR_2} = \frac{R_2 S^*}{SS^*} \tag{2.2}$$

where: H_{SR_2} is the transfer function between the source and the second receiver, and

R_2 is the complex vector in the frequency domain for the second receiver.

A third function is defined using the first two functions. It removes the source data from the equation, leaving only that which pertains to both receivers. This is presented in Equation 2.3.

$$H_{R_1R_2} = \frac{H_{SR_2}}{H_{SR_1}} \tag{2.3}$$

where: $H_{R_1R_2}$ is the calculated transfer function between the second and first receivers,

H_{SR_2} is the transfer function between the source and the second receiver,and

H_{SR_1} is the transfer function between the source and the first receiver.

Using Equations 2.4 and 2.5, the phase shift and coherence function between both receivers are calculated as follows:

$$\phi_{12} = \arctan\left\{\frac{\mathrm{Im}(H_{R_1R_2})}{\mathrm{Re}(H_{R_1R_2})}\right\} \tag{2.4}$$

where: ϕ_{12} is the phase shift between R_1 and R_2,
Im() is the imaginary part of the expression, and
Re() is the real part of the expression.

$$\gamma_{12}^2 = \frac{H_{SR_1}H_{SR_2}}{H_{R_1R_1}H_{R_2R_2}} \tag{2.5}$$

where: γ_{12}^2 is the coherence function for R_1 and R_2.

The dynamic signal analyzer was programmed to automatically calculate these transfer functions and the phase and coherence functions for receiver spacings while in the field. After the source had triggered the recording interval and that time has passed, the operator was allowed to see the source pulse recorded by the receiver array in the time domain. The operator could then either accept or reject the data. If the signal was clean, the data was accepted and the phase and coherence functions were calculated and plotted for each receiver set. Successive source pulses were measured from either the drop weight or hammer. Phase and coherence plots for each source pulse were averaged with the previous, in order to minimize noise in the data. Time histories and phase and coherence plots were shown on the screen of the analyzer during testing.

After a sufficient number of averages had been made, usually five to fifteen, the data was saved to floppy disks. All necessary data needed to rebuild phase and coherence function plots were saved in case these were inadvertently lost. This included time histories of all receivers and the source, transfer functions for each receiver with the source, and the linear spectra of the source signal.

Laboratory work compiled the data using computer software and produced experimental dispersion curves, theoretical dispersion curves, and the resulting shear wave velocity profiles. Sung-Ho Joh at The University of Texas at Austin developed the computer program, called WINSASW version 1.2.3 used for the data analysis. Using this program, phase plots were edited using the masking process, dispersion curves created, and theoretical curves matched to experimental curves by manually altering a theoretical profile.

2.2 The P-wave Refraction Testing Method

The SASW method has difficulty in resolving the velocity of deep, stiff layers, like bedrock beneath soil. In order to obtain better velocity profiles at sites with deep stiff layers p-wave refraction testing was performed at over half of the sites. Refraction field-testing used the same equipment as the SASW method. Data analysis involved selecting P-wave arrivals and calculating velocities and depths of layers. Refraction results were compared to the SASW profile and applied when applicable.

Refraction field-testing was completed on the same seismic line and using the same equipment as the SASW method. Receivers were positioned along a 122-meter

array at 7.5 meter intervals. With only three channels available on the dynamic signal analyzer, six receiver configurations were needed to cover the entire array line.
P-wave arrival times were used to create inverse velocity plots. The P-wave velocities and intercept times taken from these plots were used to calculate depths using the equations presented by Redpath (1973). Shear wave velocities were calculated from P-wave velocities assuming a Poisson's ratio of 0.3. Comparisons of depths and velocities were made between SASW and refraction methods. Velocities of deep layers identified by refraction testing were applied to the SASW half-space when applicable. Also, P-wave velocities of 1200 m/s to 1500 m/s identified depths to fully saturated zones. This information was used in the SASW inversion procedure.

Chapter 3

Site Conditions in the Wasatch Front Urban Corridor

3.1 Introduction

Our SASW measurements allowed completion of a site-conditions map for Quaternary units in Salt Lake Valley and provided preliminary data on the shear-wave-velocity characteristics of valley-margin units in the remainder of the Wasatch Front urban corridor. Our Salt Lake Valley site-conditions map is simplified from a previous site-response-unit map (Ashland and McDonald, 2003). We adopted the term *site conditions* as used by Wills and others (2000) to describe our map units; site conditions referring to the properties of shallow soils, such as impedance contrasts, that modify seismic energy. Our results in Salt Lake Valley revealed a geologic framework for mapping site conditions elsewhere in the Wasatch Front urban corridor, but Vs30 values for areas outside Salt Lake Valley suggest significant differences may exist in the shear-wave-velocity characteristics of geologically equivalent units in separate basins.

3.2 Salt Lake Valley

We made 30 new SASW measurements in deposits along the margins of Salt Lake Valley increasing the number of shear-wave-velocity measurements in these units to 65. Table 3.1 shows the distribution of these measurements in both previously mapped site-response units of Ashland and McDonald (2003) and our revised site-conditions units. We made no additional shear-wave-velocity measurements in the lacustrine and alluvial clay, silt, and sand deposits (unit Q01 of Ashland and McDonald, 2003).

Table 3.1.
Summary of SASW measurements in Salt Lake Valley Quaternary site-conditions units.

SLV units of Ashland and McDonald (2002)	Number of SASW measurements (this study)	Revised SLV units (this study)	Number of SASW measurements (this study)	Total number of shear-wave-velocity measurements
Q01	none	Q01	none	66
Q02	11	Q02	16	40
Q03	10	Q03	9	19
Q04	4	Q04	5	6
Q05	5	---	---	---

We used an iterative process to evaluate the statistical distinctiveness of previously mapped Quaternary site-response units and sub-units in Salt Lake Valley (Ashland and Rollins, 1999; Ashland and McDonald, 2003). In two cases, we determined that sub-units of one unit were better grouped into another unit. In addition, previous researchers (Ashland and Rollins, 1999; Ashland and McDonald, 2003) had mapped two possible valley-margin site-response units based solely on geologic criteria lacking shear-wave-velocity measurements in both units. Our data suggest that Vs30 in at least one of the units, pre-Bonneville alluvial-fan deposits on the west side of Salt Lake Valley (unit Q04 of Ashland and McDonald, 2003), is not necessarily distinct and does not warrant separating out the unit.

3.2.1 Unit Q02

Ashland and McDonald (2003) mapped a composite site-response unit Q02 consisting primarily of the following surficial geologic units:

1. lacustrine sand, silt, and fine gravel,
2. latest Pleistocene to Holocene alluvial-fan deposits, and
3. lacustrine clay, silt, sand, and fine gravel where overlying Holocene deposits are absent.

Ashland and McDonald (2003) mapped the unit mainly in the central and southern part of Salt Lake Valley, but also mapped isolated areas of unit Q02 in the northeastern part of the valley and in much of downtown Salt Lake City where the City Creek alluvial fan underlies the area. Ashland and McDonald (2003) characterized the unit as the most homogeneous, in terms of the distribution of Vs30, of the three Quaternary units for which shear-wave-velocity measurements existed; with all but 3 of 21 Vs30 measurements (86 percent) falling in IBC site class D.

We made eleven new SASW measurements within the previously mapped boundaries of the unit Q02. Most were in the central and southern part of the valley, but four of the measurements were in the isolated area of the unit in the northeastern part of the valley. No new measurements were made in the downtown Salt Lake City area of unit Q02. Five additional measurements in two previously mapped sub-units of the lacustrine gravel-dominated unit Q03 (figure 3.1) (Ashland and Rollins, 1999) revealed that Vs30 in the sub-units is similar to that in unit composite Q02 and justified remapping of the boundaries of unit Q02.

In only one of the former sub-units of unit Q03, the Cottonwood Delta Complex (CDC) sub-unit, did previous shear-wave-velocity measurements exist. The two previous Vs30 values in the sub-unit (Ashland and McDonald, 2003) both fall in IBC site class D and are from the distal and central parts of the delta complex. Vs30 is higher in the profile in the central part of the complex. Based on the likelihood that grain size increases toward the east and proximal parts of the delta complex, Ashland and Rollins (1999) speculated that Vs30 might also increase eastward across the sub-unit and that further subdivision of the sub-unit may be possible. However, Vs30 values from our four new shear-wave-velocity measurements made along a roughly east-trending line across the sub-unit did not increase as Ashland and Rollins (1999) speculated. Instead, Vs30 remained relatively constant varying by no more than 12 percent across the width of the delta complex. Our calculated mean Vs30 in the CDC sub-unit is 274 meters per second, similar to the mean Vs30 of 297 meters per second for unit Q02 reported by Ashland and McDonald (2003). A single Vs30 value of 311 meters per second in an unnamed lacustrine gravel-dominated sub-unit directly south of the CDC sub-unit also falls in IBC site class D and within one standard deviation of our calculated mean Vs30 of 293 meters per second for unit Q02.

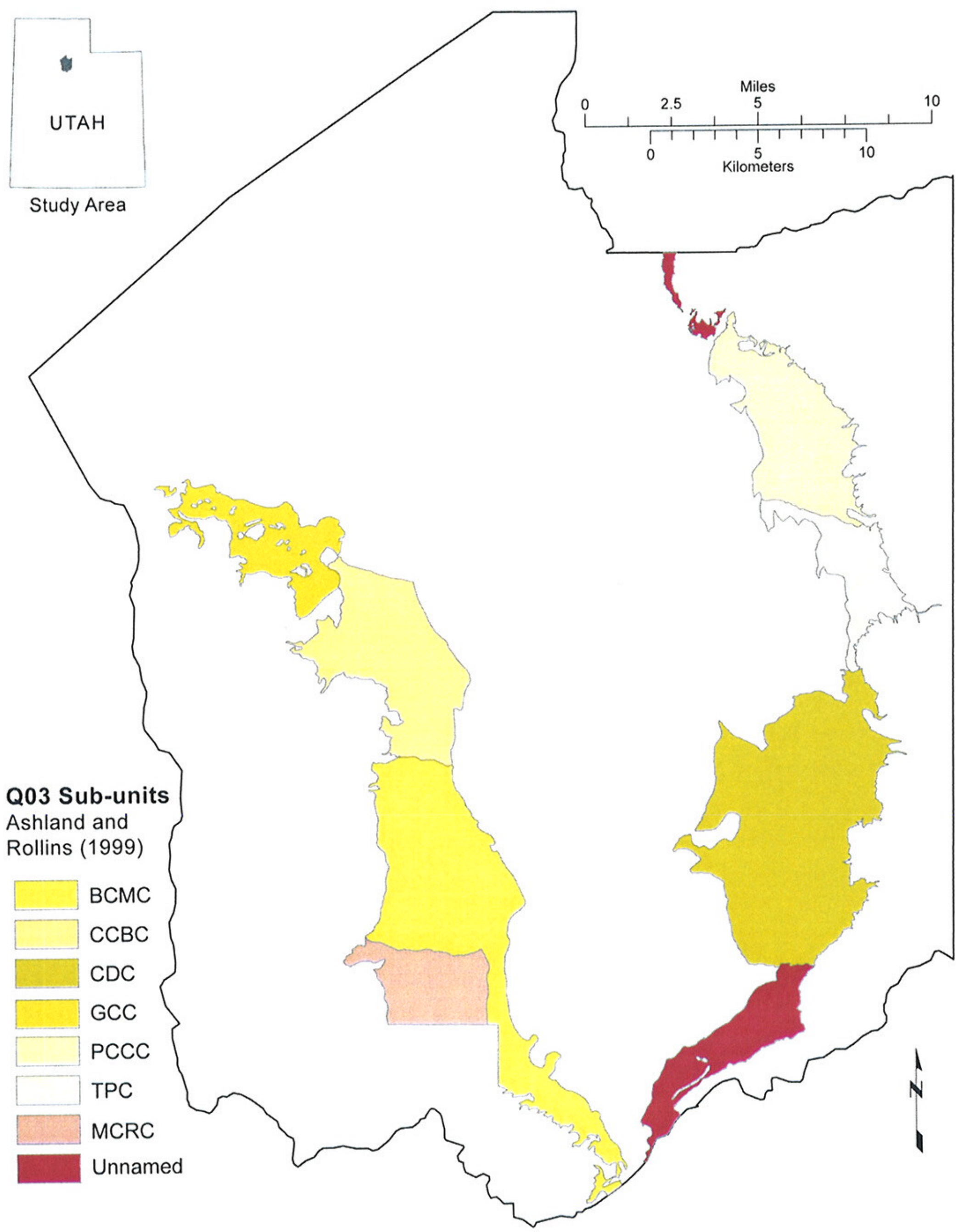

Figure 3.1. *Map showing possible sub-units of unit Q03 of Ashland and Rollins (1999). Sub-units on the west side of Salt Lake Valley are Garfield-Coon Canyons (GCC), Coon Canyon-Barneys Creek (CCBC), Barneys Creek-Midas Creek (BCMC), and Midas Creek-Rose Canyon (MCRC). East side sub-units are Parleys-City Creek Canyons (PCCC; our unit Q03a), Tolcats-Parleys Canyons (TPC), Cottonwood delta complex (CDC), and two separate unnamed sub-units in the northern and southern part of Salt Lake Valley.*

Results of statistical tests (table 3.2) on the limited data set for the CDC sub-unit and two composite sub-units consisting of combinations of the CDC sub-unit, the unnamed sub-unit to the south, and the isolated area of unit Q02 directly north of the CDC sub-unit suggest the CDC sub-unit and the composite sub-units are not distinct from unit Q02. The similarity of Vs30 in these two lacustrine gravel-dominated sub-units of Ashland and Rollins (1999) to that that in the finer grained deposits of composite unit Q02 appears related to their geologic setting in the hanging-wall block of the Wasatch fault zone. We speculate that the shear-wave-velocity characteristics of gravel-dominated units highly depend on the geologic setting relative to Holocene faults. On the hanging-wall block of a Holocene fault, Vs30 in gravel-dominated units is not distinct from that of composite unit Q02.

Table 3.2.
Statistical-test results for eastern valley-margin sub-units.

Sub-unit	Unit	t-test statistic[1]	t critical (one-tailed)	Significance (percent)	D_{KS}[2]	Significance (percent)
CDC	Q02	1.632	1.739	6.1	---	---
CDC and unnamed	Q02	1.235	1.724	11.6	---	---
Composite CDC, unnamed, and east side Q02	Q02	0.518	1.687	30.3	0.2857[3]	43.1

[1]If the t-test statistic is less than t critical, the null hypothesis that the means are equal cannot be rejected.
[2]D_{KS} is a statistic measuring the difference between the cumulative distributions.

Based on our results, we modified the boundaries of unit Q02 to include the two southeastern lacustrine gravel-dominated sub-units (CDC and the unnamed sub-unit to the south). Vs30 in our new expanded unit Q02 has a mean of 293 meters per second (table 3.3), only slightly less than the mean of 297 meters per second reported by Ashland and McDonald (2003). This suggests that the unit is adequately characterized at a regional scale. Our additional 16 measurements only reduced the mean Vs30 by less than 2 percent. Our modification of unit Q02 boundaries and the new measurements reduced the standard deviation for Vs30 by 1 percent, suggesting a slight improvement in the ability to predict shear-wave velocity. All Vs30 values derived from our 16 measurements fall between the minimum and maximum values of Ashland and McDonald (2003). In addition, our values equally straddle their median Vs30 value so that the new values barely change the median for the unit. North of downtown Salt Lake City, extractive industries (sand and gravel pits) have removed most of the valley-margin deposits. Therefore, in much of this area shown as unit Q02 on our map, Tertiary and/or Paleozoic rock may now exist at the ground surface.

Table 3.3.
Comparison of Vs30 in Quaternary unit Q02.

	Mean[1] (m/sec)	Stdev (percent)	Maximum (m/sec)	Median (m/sec)	Minimum (m/sec)	Percent IBC site class C	Percent IBC site class D	No.
This study	293	18	469	288	212	10	90	40
Ashland and McDonald (2003)	297	19[2]	469	287	212	14	86	21

[1]Logarithmic mean.
[2]Revised from Ashland and McDonald (2003).

3.2.2 Unit Q03

Ashland and McDonald (2003) mapped the gravel-dominated lacustrine and alluvial valley-margin deposits as a single site-response unit. They also characterized the shear-wave velocity of one of nine possible sub-units of Ashland and Rollins (1999), the Parleys-City Creek Canyons sub-unit in northeastern Salt Lake Valley. As discussed above, we remapped the boundaries of the unit, grouping the two southeastern sub-units and northernmost sub-unit of Ashland and Rollins (1999) into unit Q02. We made an additional 5 SASW measurements within the previously mapped boundaries (Ashland and McDonald, 2003) of unit Q03, four in the western part of Salt LakeValley. In addition, our Vs30 values for the pre-Bonneville alluvial-fan deposits along the west edge of Salt Lake Valley (unit Q04 of Ashland and McDonald, 2003) were not distinct from Vs30 in unit Q03 and warranted inclusion of this previously mapped unit in our unit Q03.

Our four shear-wave-velocity measurements in the pre-Bonneville alluvial-fan deposits along the west edge of Salt Lake Valley (unit Q04 of Ashland and McDonald, 2003) yield a mean Vs30 of 385 meters per second, nearly identical to the mean Vs30 (389 m/sec) of unit Q03 (Ashland and McDonald, 2003). The boundary between IBC site classes D and C falls within the range of Vs30 in these deposits as it does in unit Q03. The similarity in the mean and distribution of Vs30 with that of unit Q03 suggests the pre-Bonneville alluvial-fan deposits are not distinct. Table 3.4 compares Vs30 in the pre-Bonneville alluvial-fan deposits with a composite of the western sub-units of unit Q03 and summarizes Vs30 for our proposed composite unit Q03 that includes the pre-Bonneville alluvial-fan deposits and the two separate, lacustrine-gravel-dominated, sub-units on the northeast and west sides of Salt Lake Valley.

Table 3.4.
Comparison of Vs30 in gravel-dominated valley-margin sub-units.

Unit or sub-unit	Mean Vs30[1] (m/sec)	Maximum Vs30 (m/sec)	Minimum Vs30 (m/sec)	Number of Vs Profiles
Western SLV Q03	442	561	380	5
Western SLV Q04[2]	385	464	335	4
Composite western SLV Q03 and Q04 sub-unit	416	561	335	9
Q03: City Creek-Tolcats Canyons sub-unit	400	708	294	10
Q03 (this study)	407	708	294	19

[1]Logarithmetic mean.
[2]Unit Q04 of Ashland and McDonald (2003).

3.2.3 Unit Q04

Our remapping groups the pre-Bonneville alluvial-fan deposits (unit Q04 of Ashland and McDonald, 2003) with unit Q03, thus the local glacial deposits along the east side of Salt Lake Valley and in the Wasatch Range are re-designated from unit Q05 in Ashland and McDonald (2003) to unit Q04. Glacial deposits consist of both gravel-dominated alpine glacial till and outwash (Personius and Scott, 1992), but we recognize no obvious difference in Vs30 between the till and the outwash. Glacial deposits are the most localized and limited in areal extent of the four mapped Quaternary site-conditions units. Mean Vs30 based on six measurements in the unit is 456 meters per second. All Vs30 values in the unit fall in IBC site class C; the homogeneity in Vs30 distinguishing it from unit Q03. Some differences in the shear-wave-velocity characteristics may exist between the glacial deposits along the east side of Salt Lake Valley and those to the east in the Wasatch Range. However, most of those deposits occur in remote undeveloped areas.

3.2.4 Statistical Distinctiveness of Salt Lake Valley Units

Our remapping of site-conditions units in Salt Lake Valley reduced the number of Quaternary units from five (Ashland and McDonald, 2003) (table 3.5) to four (figure 3.2). Figure 3.3 compares the Vs30 distributions of the four units, showing clear differences in both the shape of the distribution, mode location, and range of Vs30. Following the methods of Park and Elrick (1998), we performed statistical tests to determine the statistical distinctiveness of the Vs30 distributions of each unit. We used a t-test for distributions with different variances to examine the differences in the means of two distributions. The use of a t-test requires that the Vs30 distribution be approximately normal. In general, the larger data sets for units Q01 and Q02 were not consistent with a normal distribution as a result of outliers, whereas the smaller data sets for units Q03 and Q04 were consistent with a normal distribution. Our use of the natural log of the Vs30 value improved the normalcy of the distributions and therefore the applicability of the t-test. For units Q01 and Q02 where the normalcy criteria was lacking but the number of

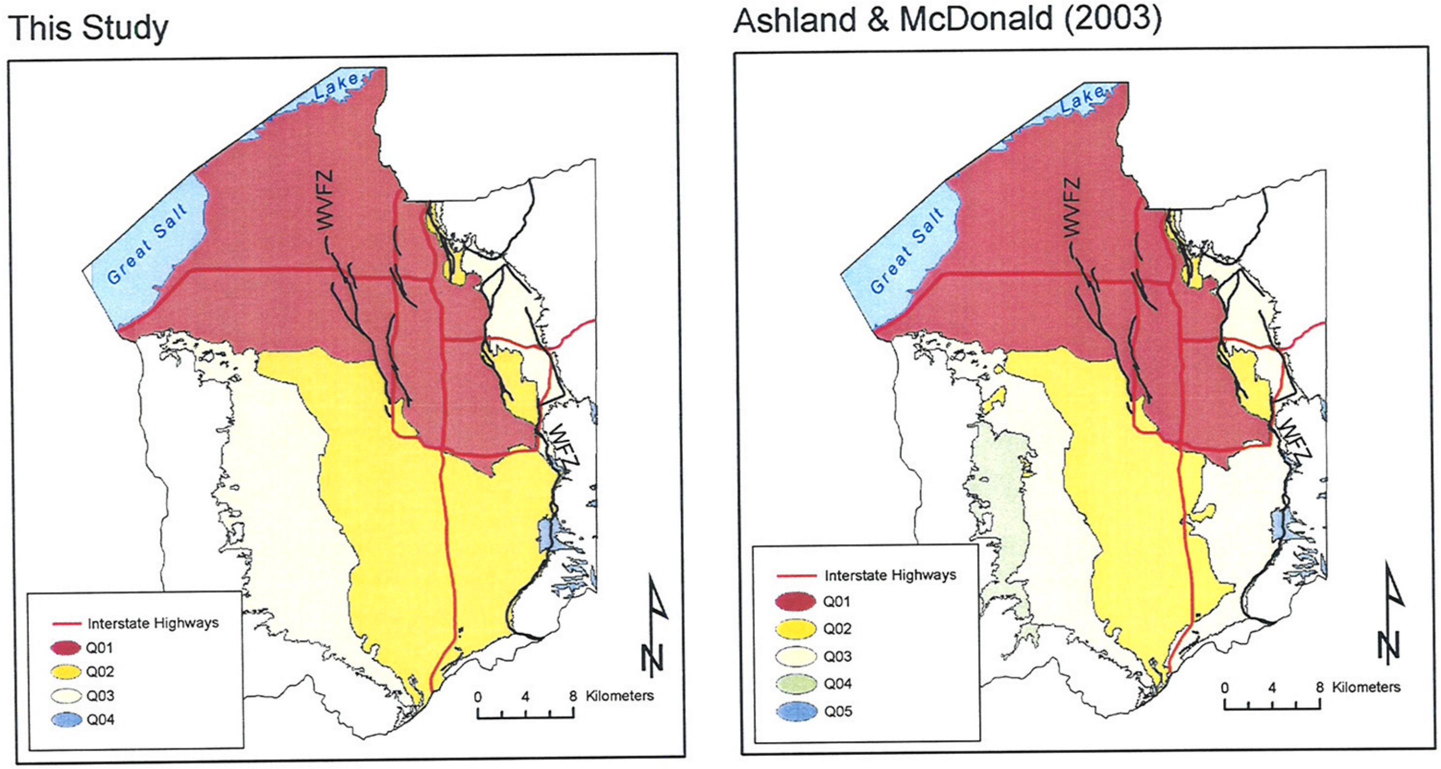

Figure 3.2. *Comparison of revised site-conditions map (this study) and previous site-response-unit map (Ashland and McDonald, 2003) of Quaternary units in Salt Lake Valley. Our revised mapping creates three distinct Quaternary units (Q01 through Q03) and a fourth unit (Q04) consisting of glacial deposits of limited areal extent on the east side of the study area. Our map expanded the area of composite unit Q02 to include gravel-dominated deltaic deposits and lacustrine shoreline deposits in the southeastern part of the valley. In addition, our results suggest that Vs30 in formerly proposed unit Q04 of Ashland and McDonald (2003) is not distinct, but overlaps with the range in Vs30 in abutting unit Q03. Our composite unit Q03 consists of gravel-dominated deposits of various ages in the footwall of Holocene faults or where Holocene faults are absent along the valley margin. See text for details on the shear-wave-velocity characteristics of the units. Abbreviations: WFZ – Wasatch fault zone, WVFZ – West Valley fault zone.*

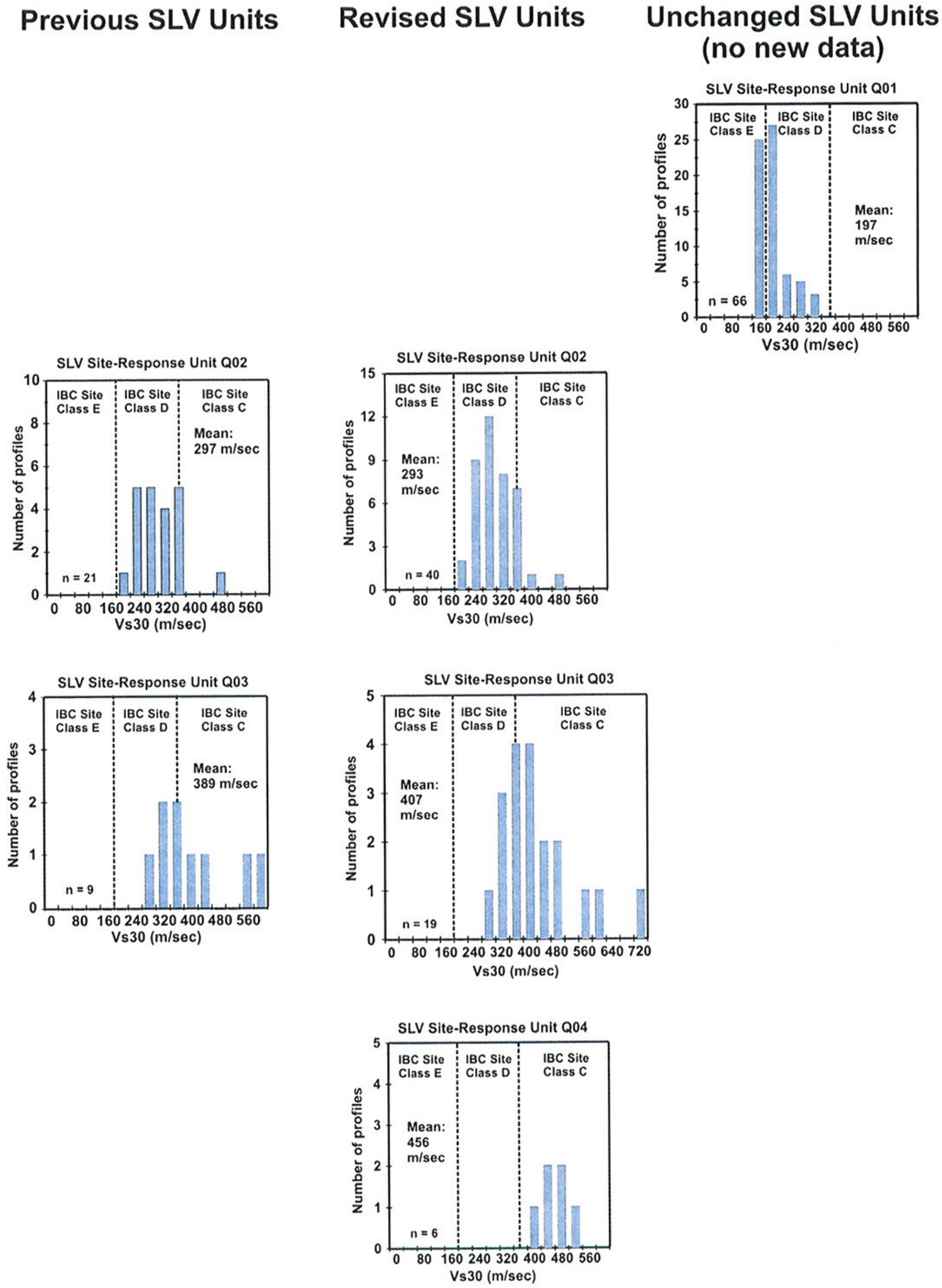

Figure 3.3. Comparison of histograms showing distribution of Vs30 in revised (this study) and previous (Ashland and McDonald, 2003) site-response units in Salt Lake Valley. In general, the new SASW measurements improved the normalcy of the Vs30 distributions for units Q02 and Q03 and yielded a normal Vs30 distribution for unit Q04 (glacial deposits) where Vs30 falls entirely within IBC site class C.

measurements exceeded 30 in both distributions, we also used a z-test, which does not require a normal distribution (Mendenhall and Sincich, 1992) to check the difference in mean Vs30. We used the Kolmogorov-Smirnov test to examine the significance of differences in the cumulative distributions. This test has the advantage of making no assumption about the distribution of the data (i.e., a normal distribution is not required). For all tests, a low significance indicates the distributions are distinct. Table 3.6 shows the results of the statistical analyses.

Table 3.5.
Summary of Vs30 for Quaternary site-response units of Ashland and McDonald (2003).

Unit	**Mean Vs30** (m/sec)	**Stdev** (percent)	**Max** (m/sec)	**Min** (m/sec)	**Median** (m/sec)	**IBC Site Class** (mean)	**Range in Site Class**	**No. of Vs Profiles**
Q01	198	22	325	151	188	D	E to D	67
Q02	297	21	469	212	287	D	D to C	21
Q03	389	31	590	260	363	C	D to C	9
Q04	estimated	--	--	--	--	--	--	0
Q05	estimated	--	--	--	--	--	--	0

Table 3.6.
Statistical-test results showing distinctiveness of proposed Salt Lake Valley Quaternary site-conditions units.

Unit	**Unit**	**t-test statistic**[1]	**t critical (one-tailed)**	**Significance (percent)**	**D_{KS}**[2]	**Significance (percent)**
Q01	Q02	10.979	1.662	<0.1	0.7682	<0.1
Q02	Q03	5.557	1.701	<0.1	0.6895	<0.1
Q03	Q04	1.853	1.713	3.8	0.6316[3]	0.3[3]

[1]If the t-test statistic is greater than t critical, the null hypothesis that the means are equal can be rejected.
[2]D_{KS} is a statistic measuring the difference between the cumulative distributions.
[3]Partly synthetic data set created for unit Q04 using a multiplier of 2.

Our review of the descriptive statistics further suggests the distinctiveness of the mean of each Quaternary site-conditions unit. Table 3.7 compares the unit mean with the third quartile statistic of the previous unit. For units Q02 and Q03, mean Vs30 falls above the third quartile value indicating that less than 25 percent of the distribution of the previous unit (Q01 and Q02, respectively) extends above the mean. In addition, the minimum Vs30 value for both units also falls above the median Vs30 for the previous unit. Thus, the Vs30 distribution of both units Q02 and Q03 overlap less than 50 percent of the distribution in the previous units. For unit Q04 (glacial deposits), mean Vs30 is slightly lower than the third quartile value in unit Q03, but the minimum value is higher than the median Vs30 for Q03. Table 3.7 also shows that the difference in mean Vs30 between units Q04 and Q03 (46 meters per second) is about half the difference between the means of the other three Quaternary units, suggesting the distinctiveness of unit Q04 from unit Q03 is less well defined. We separate out the glacial deposits as a single Quaternary site-conditions unit based partly on other criteria, including the homogeneity in IBC site class of the limited Vs30 measurements (all are IBC site class C), the limited areal extent and isolated nature of the deposits, and the lack of geologic characteristics that would allow the unit to be obviously grouped with another site-conditions unit. Table 3.8 summarizes Vs30 in the four Salt Lake Valley Quaternary site-conditions units.

Table 3.7.
Comparison of descriptive statistics for Salt Lake Valley Quaternary site-conditions units.

Unit	3rd Quartile (m/sec)	Median (m/sec)	Unit	Mean (m/sec)	Minimum (m/sec)	Difference in means (m/sec)
Q01	215	188	Q02	293	212	96
Q02	334	288	Q03	407	294	114
Q03	464	394	Q04	456	413	49

Table 3.8.
Summary of Vs30 for Salt Lake Valley Quaternary site-conditions units.

Unit	Mean Vs30 (m/sec)	Stdev (percent)	Max (m/sec)	Min (m/sec)	Median (m/sec)	IBC Site Class (mean)	Range in Site Class	No. of Vs Profiles
Q01	197[1]	19[1]	325	151	188[1]	D	E to D	66
Q02	293	18	469	212	288	D	D to C	40
Q03	407	25	708	294	394	C	D to C	19
Q04	456	7	510	413	459	C	C	6

[1]Revised from Ashland and McDonald (2003).

3.2.5 Geologic Framework Implications

The latest measurements and the results of this study provide an improved geologic framework for predicting shear-wave velocities, specifically Vs30, of surficial geologic units in the Wasatch Front. Previous studies (Williams and others, 1993; Ashland and Rollins, 1999; Ashland and McDonald, 2003) recognized a relation between dominant grain size and shear-wave velocity. This study confirms that dominant grain size is an important factor, but recognizes geologic setting, specifically the relation of the units to the Holocene faults, as another important consideration in predicting shear-wave velocity. Gravel-dominated lacustrine and alluvial deposits in the footwall of Holocene faults (our unit Q03) or where Holocene faults are absent (west edge of Salt Lake Valley) have higher shear-wave velocities than similar deposits in the hanging wall of such faults (CDC and unnamed sub-units of unit Q03 of Ashland and Rollins, 1999). The higher shear-wave velocities in gravel-dominated deposits in the footwall of Holocene faults or where Holocene faults are absent are likely the result of a combination of conditions in this geologic setting, including:

1. the presence of shallow, weathered rock,
2. the presence of shallow, semi-consolidated sediments including Tertiary (Neogene) valley fill, and
3. the presence of tufa-cemented sediments.

These conditions, with the exception of the local occurrence of tufa cementation, are generally absent in the hanging wall of Holocene faults, where late Quaternary deposits are inferred to be over 30 meters thick (Arnow and others, 1970; Wong and others, 2002). Higher shear-wave velocities do not occur where older deposits, such as the pre-Bonneville alluvial-fan deposits along the west edge of Salt Lake Valley, crop out at the surface, suggesting the age of surficial deposits is secondary to grain size and other factors in predicting shear-wave velocity. In most of unit Q03, older deposits (semi-consolidated sediments), if present, occur in the subsurface beneath late Pleistocene to Holocene deposits.

Two other Quaternary units (Q01 and Q02) in Salt Lake Valley occur mostly in the hanging wall of the Salt Lake City segment of the Wasatch fault zone. Differences in shear-wave velocity between these units are mostly attributable to dominant grain size. However, variations in the grain size of the surficial geologic unit are characteristic of the composite site-conditions unit Q02, despite the smallest standard deviation in Vs30 of the three largest Quaternary units. Ashland and McDonald (figure 5, 2003) showed that the range in Vs30 overlapped for the three grain-size-defined sub-units. Variation in Vs30 in Salt Lake Valley Quaternary units is likely related to complex interbedding and interfingering of facies. Based on the observed relation between shear-wave velocity and grain size (Ashland and Rollins, 1999; Ashland and McDonald, 2003), we infer that an increase in Vs30 occurs with an increase in the relative abundance of the coarse-grained facies in the upper 30 meters. However, the highest mean Vs30 for the separate surficial units within unit Q02 occurs where the generally fine-grained lacustrine silt and clay deposits are at the surface. This suggests that prediction of the relative abundance of the coarser facies in the upper 30 meters is not possible solely based on the dominant grain size of the surficial unit, but requires a detailed 3-dimensional facies model for the valley that is currently lacking.

3.3 Other Wasatch Front Valleys

We made a total of 14 SASW measurements in Quaternary units in the Wasatch Front urban corridor outside of Salt Lake Valley. Our additional measurements more than tripled the total number of Vs30 measurements in the remainder of the urban corridor. The data suggest possible differences in the shear-wave-velocity characteristics of the Quaternary units elsewhere in the Wasatch Front and those of units in Salt Lake Valley.

3.3.1 Davis County

The Davis County part of the Wasatch Front urban corridor can be divided into two parts: a northernmost part that includes the southern part of the Weber River delta that formed in Late Pleistocene Lake Bonneville, and a southern part that consists of a relatively narrow band of lacustrine deposits of Late Pleistocene Lake Bonneville mostly in the hanging wall of the Weber segment of the Wasatch fault zone (figure 3.4). We discuss the surficial geology and shear-wave-velocity characteristics of the northern part of the county in the section on Weber County where the surficial geology of the Ogden area of the county is dominated by the composite Weber and Ogden Rivers delta. We chose Hobbs Creek near the southern edge of the delta as the boundary between the two parts of the county.

Most of the Davis County part of the Wasatch Front urban corridor consists of a relatively narrow strip of land between Great Salt Lake and the Wasatch Range (figure 3.4). At its narrowest, this part of the urban corridor is less than 3.5 kilometers wide. The area is underlain by lacustrine deposits of Late Pleistocene Lake Bonneville that consist of fine-grained sediments in the west and sand- and gravel-dominated shoreline deposits in the east along the base of the Wasatch Range that are locally overlain by latest Pleistocene to Holocene alluvium and alluvial-fan deposits. In addition, local landsliding and earthquake-induced lateral spreading has occurred in these deposits during the Holocene. The largest known lateral spread is the Farmington Siding landslide (Van Horn, 1975; Hylland and Lowe, 1998). Hylland and Lowe (1998) documented that the landslide has been recurrently active; landsliding likely being triggered by surface-faulting earthquakes on the nearby Weber segment of the Wasatch fault zone.

In Davis County, our study focused on valley margin units. We made no measurements in the fine-grained lacustrine units in the western part of the county, although three shear-wave-velocity profiles exist in the unit.

3.3.1.1 Davis County $Q02_{DC}$: Solomon and others (2004) mapped the lacustrine shoreline and intermixed alluvial deposits in the eastern side of Davis County as two separate site-response units: a sand-dominated unit and a gravel-dominated unit. We made three shear-wave velocity measurements in these units: two in their sand-dominated unit and one in their gravel-dominated unit. Vs30 at all three sites clusters near a mean of 299 meters per second suggesting the two units of Solomon and others (2004) could possibly be grouped into a single site-conditions unit equivalent to our revised unit Q02 in Salt Lake Valley. Figure 3.3 shows a possible site-conditions map for southern Davis County that includes only two Quaternary units.

3.3.2 Northern Davis County and Weber County

Weber County is currently in the northern part of the Wasatch Front urban corridor and includes the city of Ogden. The surficial geology of both northern Davis County and Weber County is dominated by the composite Weber-Ogden Rivers delta that formed along the east edge of Late Pleistocene Lake Bonneville. In addition to the prehistoric delta, a modern delta is currently being formed in the westernmost part of Weber County by the deposition of fine-grained sediments by these rivers into Great Salt Lake. We refer to the prehistoric delta that formed along the east edge of Lake Bonneville as the composite Weber-Ogden Rivers delta. Most of the deltaic deposits mapped by Nelson and Personius (1993) formed when Lake Bonneville was at the Provo level between about 16,800 and 16,200 years ago. Solomon and others (2004) mapped the sand- and silt-dominated deltaic deposits as part of the sand-dominated site-response unit and

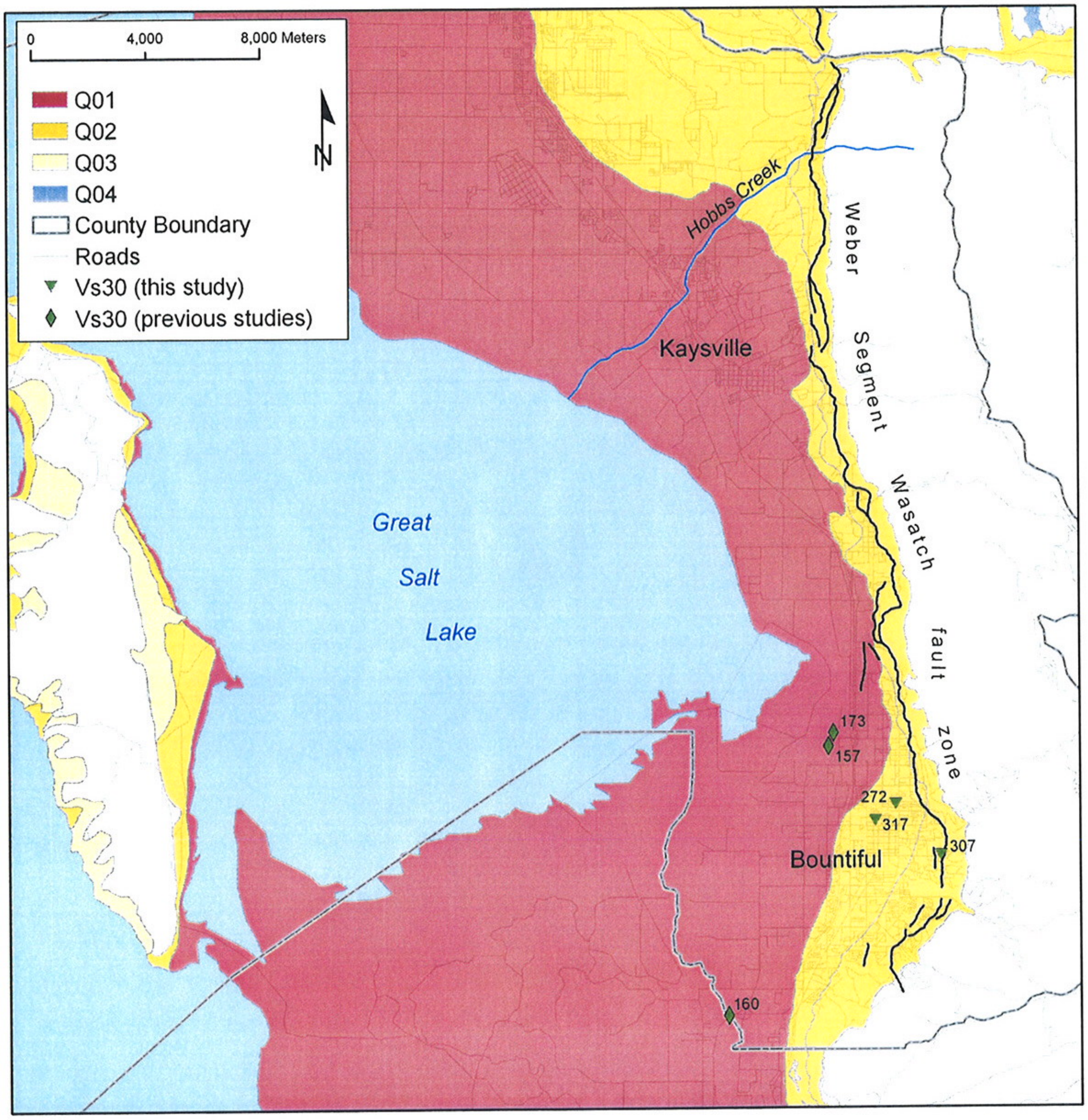

Figure 3.4. *Possible site-conditions map of the urban corridor in Davis County south of Hobbs Creek. Quaternary units consist of lacustrine clay, silt, and sand (unit* $Q01_{DC}$*) where Vs30 is dominantly within IBC site class E, and gravel- and sand-dominated lacustrine shoreline deposits (unit* $Q02_{DC}$*) where Vs30 falls mostly in IBC site class D. The county line defines the southern boundary of the area. We selected Hobbs Creek as the approximate northern boundary. Vs30 data in unit Q01 from unpublished shear-wave-velocity profiles provided by the Utah Department of Transportation.*

mapped gravel-dominated shoreline deposits and alluvium along the base of the mountains as a separate site-response unit.

3.3.2.1 Northern Davis County and Weber County Unit $Q02_{WC}$: We made three shear-wave-velocity measurements in the deltaic deposits (lacustrine sand, silt, and clay unit of Solomon and others, 2004) in the Ogden area (figure 3.5). Vs30 at all three sites clusters near a mean of 197 meters per second, nearly identical to the mean of unit Q01 in Salt Lake Valley. A fourth downhole shear-wave-velocity measurement by LGS Geophysics Inc. (1997) yields a higher Vs30 value of 256 meters per second. The four shear-wave-velocity profiles yield a mean Vs30 of 210 meters per second that is below the minimum value for unit Q02 in Salt Lake Valley.

These preliminary measurements suggest that the shear-wave velocities of the predominantly lacustrine units in the Ogden area may be considerably lower than in Salt Lake Valley. We speculate that future shear-wave-velocity measurements will reveal either three distinct site-conditions units in the Ogden area, all with lower shear-wave velocities and mean Vs30 than in Salt Lake Valley, or two units similar to units Q01 and Q02 in Salt Lake Valley (figure 3.5). In the latter case, the deltaic deposits in the Ogden area would fall in a different site-conditions unit than the deltaic deposits in Salt Lake Valley.

3.3.3 Northern Utah County

Northern Utah County is currently in the southern part of the Wasatch Front urban corridor and can be divided into two distinct parts: eastern Utah Valley and Cedar Valley/western Utah Valley. The surficial geologic units in eastern Utah Valley consist mostly of lacustrine deposits of Late Pleistocene Lake Bonneville overlain locally by latest Pleistocene to Holocene alluvium and alluvial-fan deposits. In general, these units are in the hanging wall of the Provo segment of the Wasatch fault zone where unconsolidated Quaternary deposits exceed 30 meters in thickness (Solomon and others, 2004). Cedar Valley in the northwestern part of Utah County has no mapped Quaternary faults on its margins, but older buried faults likely exist along the eastern and western margins (Hurlow, 2004). The surficial geologic units in western Utah Valley and Cedar Valley consist of pre-Bonneville alluvial-fan deposits and lacustrine deposits of Late Pleistocene Lake Bonneville. Local latest Pleistocene to Holocene alluvium, alluvial-fan deposits, and loess overlie the lacustrine deposits.

In Utah County, our study focused on valley-margin units. We made no measurements in the fine-grained lacustrine units along Utah Lake or the sand-dominated lacustrine deposits in the central part of Cedar Valley. We also made no measurements in the glacial deposits because of their limited areal extent, location in a mostly undeveloped area, and access difficulty.

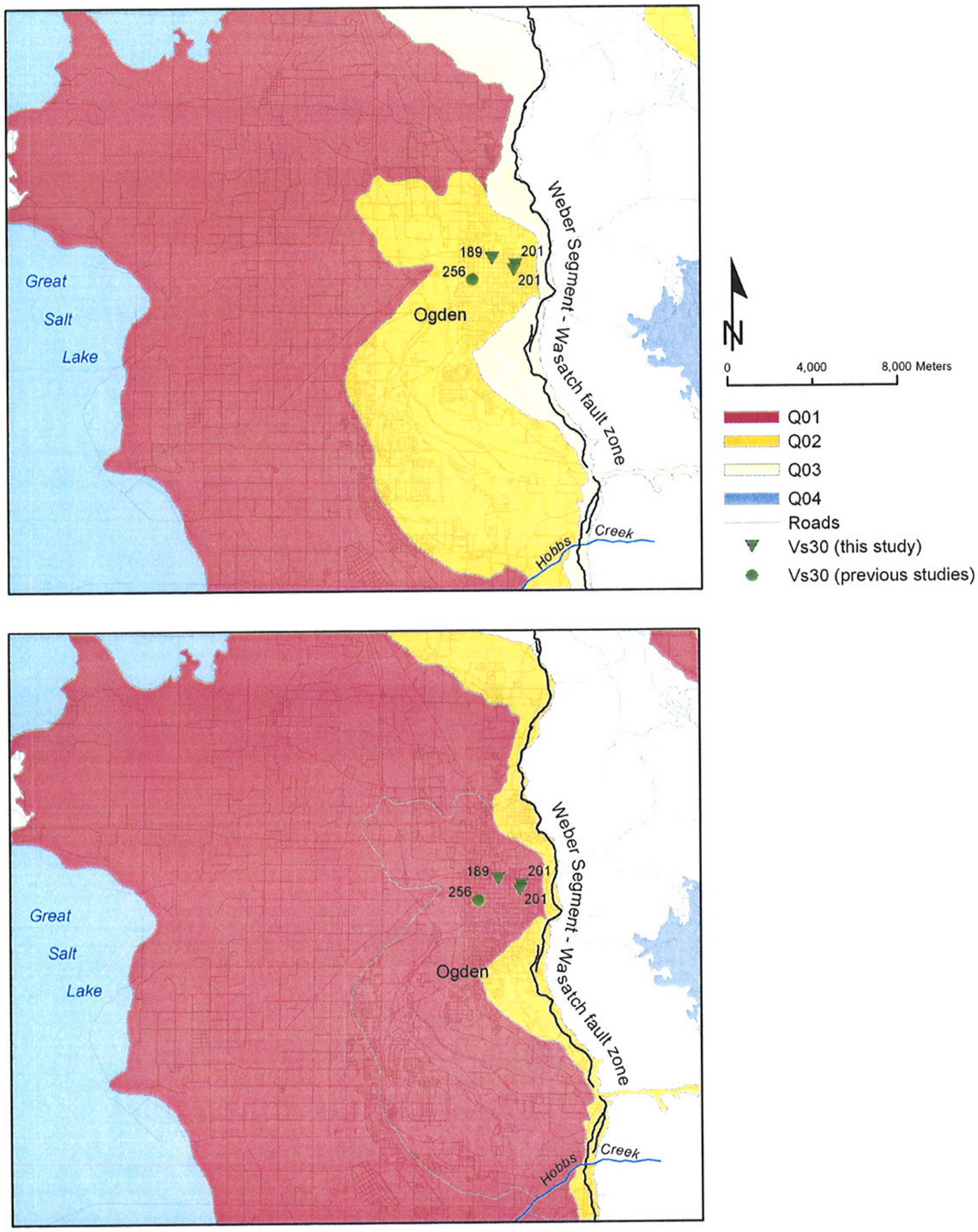

Figure 3.5. *Comparison of two possible site-conditions maps for Weber and northern Davis Counties. Upper map shows three distinct Quaternary units west of the Wasatch fault zone (units $Q01_{WC}$ through $Q03_{WC}$). Unit $Q02_{WC}$ is inferred to have similar shear-wave-velocity characteristics to unit Q01 in Salt Lake Valley. Vs30 in unit $Q01_{WC}$ is inferred to fall dominantly in IBC site class E. Lower map shows only two distinct Quaternary units west of the Wasatch fault zone (units $Q01_{WC}$ and $Q02_{WC}$). Lacustrine deltaic deposits in the Ogden area are included in unit $Q01_{WC}$.*

3.3.3.1 Utah Valley $Q02_{UC}$: Solomon and others (2004) mapped the gravel-dominated alluvium and lacustrine shoreline deposits and sand-dominated deltaic deposits in the eastern side of Utah Valley as two separate site-response units. We made three shear-wave-velocity measurements in these units: one in the sand-dominated unit and two in the gravel-dominated unit. Vs30 at all three sites clusters near a mean of 336 meters per second suggesting the two units of Solomon and others (2004) could be grouped into a single site-conditions unit equivalent to our revised unit Q02 in Salt Lake Valley (figure 3.6).

3.3.3.2 Cedar Valley and western Utah Valley margin unit $Q03_{UC}$: Cedar Valley is in northwestern Utah County west of Utah Lake and the Lake Mountains. The valley is bounded on several sides by mountains consisting mostly of Paleozoic sedimentary rocks that are locally intruded by igneous rocks and/or capped by volcanic rocks. Unconsolidated surficial units in the center of the valley consist of sand-dominated lacustrine deposits associated with Late Pleistocene Lake Bonneville. Unconsolidated surficial units in the valley margins consist of pre-Bonneville alluvial-fan deposits and gravel-dominated lacustrine shoreline deposits.

We measured shear-wave velocities at four sites in the valley-margin unit: two in the northern part of the valley and two in the northern part of the eastern edge of the valley along the west flank of the Lake Mountains (figure 3.6). Two of the measurements were in pre-Bonneville alluvial-fan deposits and two were in gravel-dominated lacustrine shoreline sediments. At all four sites Vs30 fell in IBC site class C and mean Vs30 is 502 meters per second. The range in Vs30 of the latter brackets Vs30 in the former suggesting Vs30 in the two valley-margin units is not distinct. Thus, we grouped the two geologically distinct units into a single site-conditions unit $Q03_{UC}$. Whereas we made no measurements in the valley-margin units in western Utah Valley, we speculate that the area has similar shear-wave-velocity characteristics to Cedar Valley.

The high mean Vs30 for the Cedar Valley margin unit is in part due to the presence of rock or rock-like material at a depth shallower than 30 meters. Both shear-wave-velocity profiles in the pre-Bonneville alluvial-fan deposits encountered a layer with a shear-wave velocity greater than 760 meters per second in the upper 30 meters. Solomon and others (2002) estimated that most of the Quaternary surficial geologic valley-margin units are less than 30 meters deep and rarely exceed 40 meters in thickness. An isopach map of Tertiary (Neogene) and younger valley-fill deposits (Hurlow, 2004) indicates sediment thickness ranges up to 300 meters in the valley margin. Thus, the lower part of the shear-wave-velocity profiles may be in semi-consolidated Tertiary (Neogene) valley-fill deposits that are locally shallower than 30 meters in depth. We calculated the average shear-wave velocity of the soil column above the high-velocity layers in each profile. Table 3.9 compares the average shear-wave velocity of the soil column above the high-velocity layers to Vs30 in the Cedar Valley margin unit.

Table 3.9.
Comparison of the average shear-wave velocity of the soil column to Vs30 for unit $Q03_{UC}$.

Unit or sub-unit	Vs30 (m/sec)	IBC Site Class	Max Vs30 (m/sec)	Min Vs30 (m/sec)	VsSC[1] (m/sec)	Max VsSC[1] (m/sec)	Min VsSC[1] (m/sec)
Cedar Valley Q03	502	C	640	434	453	501	427
Utah County Q03	487	C	640	431	430	501	351

[1]VsSC is the average shear-wave velocity of the soil column above the high-velocity layers.

3.3.3.3 Utah Valley $Q03_{UC}$: We made one additional shear-wave-velocity measurement in pre-Bonneville alluvial-fan deposits in Utah County near Alpine, Utah (figure 3.6). The Vs30 at this site is 431 meters per second, similar to the Vs30 of the same deposit in northern Cedar Valley, suggesting that the shear-wave-velocity characteristics of the pre-Bonneville alluvial-fan deposits on the east side of Utah Valley may be similar to those of the Cedar Valley margin unit. Table 3.9 (Utah County Q03) shows the slight changes to the Vs30 statistics with the addition of the Alpine area shear-wave-velocity measurement.

3.3.4 Summary

The preliminary data suggest that mapped site-conditions units elsewhere in the Wasatch Front urban corridor may have different shear-wave-velocity characteristics than the geologically equivalent units in Salt Lake Valley. Table 3.10 compares mean Vs30 for six equivalent site-conditions units elsewhere in the Wasatch Front urban corridor, grouping each with the most closely matching unit in Salt Lake Valley. The apparent difference in the shear-wave velocities of equivalent units in and outside Salt Lake Valley may be due in part to geologic differences in the sediment source areas. Major drainages in Weber and Davis County erode Tertiary sedimentary and Precambrian metamorphic rocks, whereas the major drainages in Salt Lake Valley mostly erode Tertiary granitic and Paleozoic through Mesozoic sedimentary rocks. As a result, the valley fill in other Wasatch Front basins is finer grained than in Salt Lake Valley. Another factor contributing to the finer grained valley fill in other Wasatch Front basins is that deposition occurs in distal parts of large, low gradient drainages such as the Provo, Weber, and Ogden Rivers. In Salt Lake County, shorter, steeper drainages generally deliver coarser sediment.

Based on the anticipated differences in shear-wave velocities, defining distinct site-conditions units that span the entire Wasatch Front urban corridor may not be practicable. Instead, the data suggest that separate units may be required for each major basin area. Our approach in this report was to map out the likely grouping of basin-specific site-conditions units using the available data.

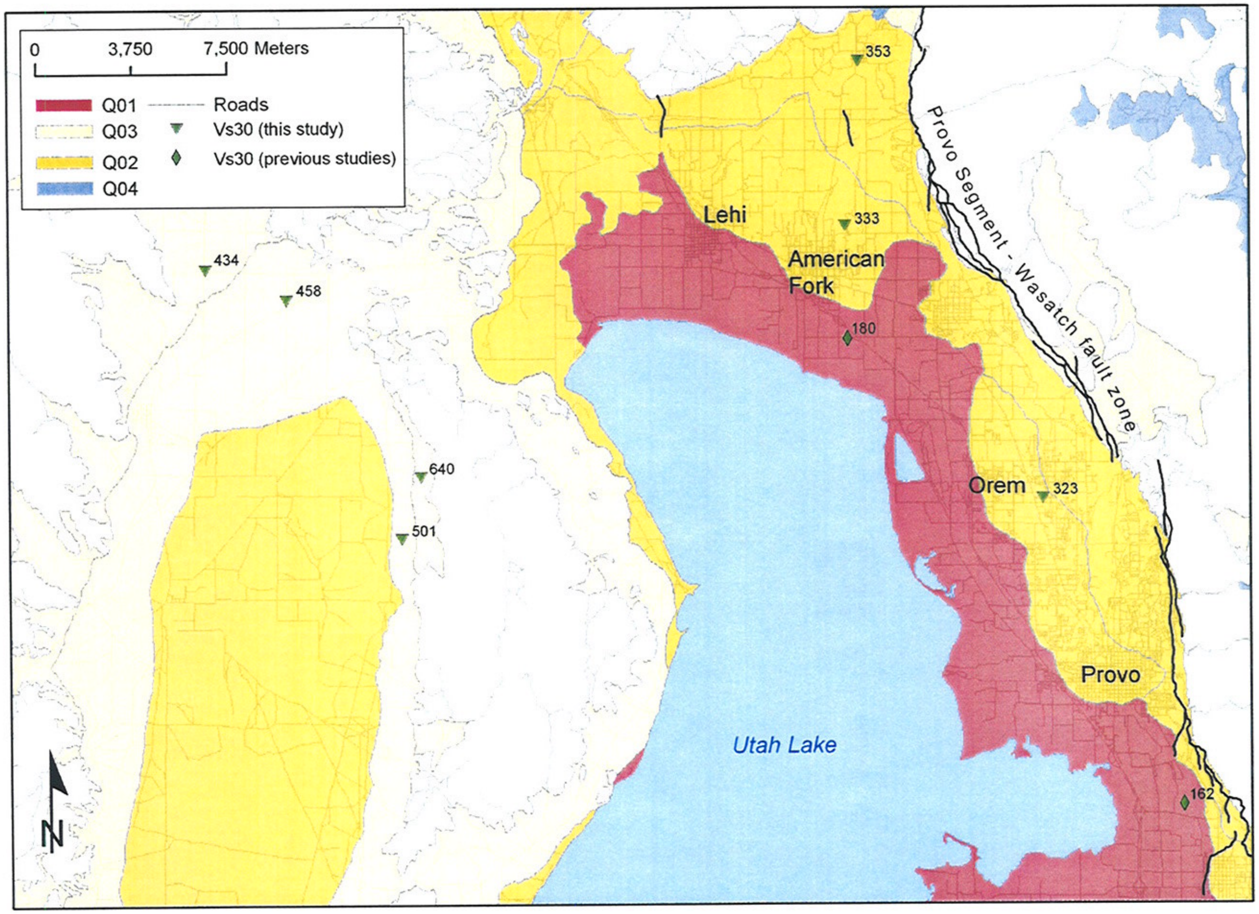

Figure 3.6. *Map showing possible site-response units in northern Utah County. Quaternary units consist of lacustrine clay, silt, and sand (unit $Q01_{UC}$) where Vs30 is dominantly within IBC site class E, sand- and gravel-dominated lacustrine shoreline deposits (unit $Q02_{UC}$) where Vs30 falls mostly in IBC site class D, gravel-dominated lacustrine and pre-Bonneville alluvial-fan deposits (unit $Q03_{UC}$) where Vs30 straddles the boundary between IBC site classes D and C, and glacial deposits (mostly in the Wasatch Range) where Vs30 likely falls in IBC site class C. Vs30 values in unit Q01 from unpublished UGS data.*

Table 3.10.
Comparison of Wasatch Front and Salt Lake Valley Vs30.

SLV Unit	Mean Vs30 (m/sec)	IBC Site Class (mean)	Max (m/sec)	Min (m/sec)	No. of Vs Profiles	Wasatch Front Unit	Mean Vs30 (m/sec)	IBC Site Class (mean)	No. of Vs Profiles
Q01	197	D	325	151	66	**Q01:** Davis Co.	163	E	3
						Q01: Utah Co.	171	E	2
						Q02: Weber Co.	197 to 210	D	3-4
Q02	293	D	469	212	40	**Q02 and Q03:** Davis Co.	298	D	3
						Q03: Davis Co.	307	D	1
Q03	407	C	708	294	19				
Q04	456	C	510	413	6	**Q03 and Q04:** Cedar Valley	502	C	4

Appendix

Measured Shear Wave Velocity Profiles

This Appendix presents results of SASW and refraction testing performed during the summer and fall of 2003 at 44 sites in the Salt Lake Valley, and surrounding areas. Results for each of the 44 sites tested are presented in this chapter. Locations of each site are shown graphically, and GPS coordinates are listed. Experimental and theoretical dispersion curves are presented, as well as the shear wave velocity profiles. Refraction testing data is also shown, if completed. Phase plots for each of the sites can be found in the appendix.

North Hang Glider Park

The North Hang Glider Park site, referenced as Site 300 in Fig. A.1, is located at the southeastern end of Salt Lake Valley on a bench of the prehistoric Bonneville Lake shoreline. This site was previously mapped in the Q03 site response unit by Ashland (2001). A map showing the location of the site is shown in Fig. A.1 and a photograph of the site is shown in Fig. A.2. The coordinates (UTM WGS84) of the center of the SASW testing array are 4480498 North and 424311 East at approximately 1,569 m above sea level.

The multiple-page Appendix is available through the USGS Library in paper form. The location is noted on the first page of this report